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## TRANSLATION CERTIFICATION

This is a complete and accurate translation by us, to the best of our knowledge and ability, from German into English of:

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METHOD FOR THE CLOSED-LOOP SPEED CONTROL OF AN INTERNAL  
COMBUSTION ENGINE

The invention concerns a method for the closed-loop speed control of an internal combustion engine in accordance with the introductory clause of Claim 1.

The speed of a drive unit is typically automatically controlled to an idling speed and a final speed. A drive unit is understood to mean either an internal combustion engine-transmission unit or an internal combustion engine-generator unit. To achieve closed-loop speed control, the speed of the crankshaft is detected as a controlled value and compared with an engine speed set value, i.e., the reference input. The resulting control deviation is converted by a speed controller to a correcting variable for the internal combustion engine, for example, an injection quantity. The problem with a control loop of this type is that torsional oscillations, which are superimposed on the controlled value, can be amplified by the speed controller. This can lead to instability of the closed-loop control system

The problem of instability is countered by a speed filter in the feedback path of the closed-loop speed control system. EP 0 059 585 B1 describes a speed filter of this type, in which the timing values of a shaft teeth are detected by means of an operating cycle of the internal combustion engine. The operating cycle is defined as two revolutions of the crankshaft, corresponding to 720°. These tooth timing values are then used to calculate a filtered tooth timing value by taking the arithmetic mean. This filtered tooth timing value corresponds to the filtered actual speed value, which is then used for the automatic control of the internal

combustion engine.

A closed-loop speed control system for automatically controlling a drive unit with a speed filter of this type in the feedback path is described, for example, in DE 199 53 767 C2.

However, the problem with this two-revolution filter in the feedback path is that stable behavior of the drive unit is accompanied by deterioration of the design load behavior.

The goal of the invention is to optimize the closed-loop speed control system with respect to design load behavior.

This goal is achieved by the features of Claim 1. Refinements of the invention are specified in the dependent claims.

In accordance with the invention, a second filter is used to compute a second filtered actual speed from the actual speed of the internal combustion engine, and then a second control deviation is computed from this second filtered actual speed. In the event of a dynamic change of state, the speed controller computes a power-determining signal, for example, an injection quantity, from the first and second control deviations. In this regard, the power-determining signal in the event of a dynamic change of state is substantially determined from the second control deviation.

A dynamic change of state occurs when a large deviation between set and actual speed values is present, for example, when a load application or load rejection occurs. The second filter is realized, e.g., as a mean value filter with a filter angle of  $90^\circ$ , for fast detection of this dynamic event. Compared to the two-revolution filter, a filtered speed value is present at a significantly earlier point in time, i.e., the dynamic change of state is detected faster.

The invention offers the advantage that couplings with a low natural frequency can be used. Since the second filter constitutes a pure software solution, it can be subsequently

integrated in already existing engine control software.

When a dynamic change of state occurs, the second control deviation acts on a proportional component (P component) or a DT1 component of the speed controller. Suitable characteristic curves are provided for this purpose.

Preferred embodiments of the invention are illustrated in the drawings.

- Figure 1 shows a system diagram;
- Figure 2 shows a closed-loop speed control system;
- Figure 3 shows a functional block diagram of the speed controller;
- Figure 4 shows a characteristic curve;
- Figure 5 shows a functional block diagram of the speed controller (second embodiment); and
- Figure 6 shows a characteristic curve.

Figure 1 shows a system diagram of the overall system of a drive unit 1, for example, an internal combustion engine-generator unit. It comprises an internal combustion engine 2 with an engine load 4. The internal combustion engine 2 drives the engine load 4 via a shaft with a transmission element 3. In the illustrated internal combustion engine 2, the fuel is injected by a common-rail injection system. This injection system comprises the following components: pumps 7 with a suction throttle for conveying the fuel from a fuel tank 6; a rail 8 for storing the fuel; and injectors 10 for injecting the fuel from the rail 8 into the combustion chambers of the internal combustion engine 2.

The internal combustion engine 2 is automatically controlled by the electronic control unit (EDC) 5. The electronic control unit 5 contains the usual components of a microcomputer system, for example, a microprocessor, interface adapters, buffers, and memory components

(EEPROM, RAM). The relevant operating characteristics for the operation of the internal combustion engine 2 are applied in the memory components in input-output maps/characteristic curves. The electronic control unit 5 uses these to compute the output variables from the input variables. Figure 1 shows the following input variables as examples: a rail pressure  $p_{CR}$ , which is measured by means of a rail pressure sensor 9; an actual speed  $n_M(IST)$  of the internal combustion engine 2; an input variable  $E$ ; and a signal  $FP$  for the power presetting by the operator. In a motor vehicle application, this corresponds to the position of the accelerator pedal. Examples of input variables  $E$  are the charge air pressure of the turbochargers and the temperatures of the coolant/lubricant and the fuel.

As output variables of the electronic control unit 5, Figure 1 shows a signal  $ADV$  for controlling the pumps 7 with a suction throttle and an output variable  $A$ . The output variable  $A$  is representative of the other control signals for automatically controlling the internal combustion engine 2, for example, the injection start  $SB$  and a power-determining signal  $ve$ , which corresponds to the injection quantity.

Figure 2 shows a functional block diagram of the closed-loop speed control system. The input variable of the closed-loop speed control system is a set speed  $n_M(SL)$ . The output variable of the closed-loop speed control system is the unfiltered actual speed  $n_M(IST)$ . A first filter 12 for computing the first actual speed  $n_{M1}(IST)$  from the current unfiltered actual speed  $n_M(IST)$  is provided in a first feedback path. The first filter 12 is usually designed as a two-revolution filter, i.e., it averages the actual speed  $n_M(IST)$  over one operating cycle corresponding to  $720^\circ$  of the crankshaft. A second filter 13 for computing a second actual speed  $n_{M2}(IST)$  from the current unfiltered actual speed  $n_M(IST)$  is provided in a second feedback path. The second filter 13 is realized, e.g., as a mean value filter with a filter angle of a  $90^\circ$

crankshaft angle. The second filter 13 thus has significantly greater dynamics than the first filter 12.

A first control deviation  $dR1$  is computed at a first comparison point A. It is determined from the set speed  $nM(SL)$  and the first actual speed  $nM1(IST)$ . The first control deviation  $dR1$  is the input variable of the speed controller 11. A second control deviation  $dR2$  is computed at a second comparison point B. It is determined from the set speed  $nM(SL)$  and the second actual speed  $nM2(IST)$ . The second control deviation  $dR2$  is also supplied to the speed controller 11. The internal structure of the speed controller 11 will be explained in connection with the description of Figures 3 and 5. The speed controller 11 determines a correcting variable from the input variables. In Figure 2, this correcting variable is designated as a power-determining signal  $ve$ . The power-determining signal  $ve$  represents the input variable for the controlled system, which in the present case is the internal combustion engine 2. The output variable of the controlled system corresponds to the unfiltered actual speed  $nM(IST)$ . The automatic control system is thus closed.

The invention is designed in such a way that during steady-state operation of the drive unit, the speed controller 11 computes the power-determining signal  $ve$  exclusively as a function of the first control deviation  $dR1$ . When a dynamic change of state occurs, the speed controller 11 determines the power-determining signal  $ve$  as a function of the first control deviation  $dR1$  and the second control deviation  $dR2$ .

Figure 3 shows a functional block diagram that represents a first embodiment of the internal structure of the speed controller 11. The speed controller 11 comprises a proportional component (P component) 15 for determining a proportional component  $ve(P)$  of the power-determining signal  $ve$ , an integral-action component (I component) 16 for determining an

integral-action component  $ve(I)$  of the power-determining signal  $ve$ , a characteristic curve 14, and a summation unit 18. The first control deviation  $dR1$  is the input variable for the P component 15 and the I component 16. The second control deviation  $dR2$  is supplied to the characteristic curve 14. The output variable of the characteristic curve 14 is a factor  $kp2$ , which acts on the P component 15. Another input variable of the P component 15 is a factor  $kp1$ . The characteristic curve is shown in Figure 4. Values of the second control deviation  $dR2$  are plotted in the positive/negative direction on the x-axis. The y-axis represents the factor  $kp2$ . A first limiting value  $GW1$  and a second limiting value  $GW2$  are plotted on the x-axis. At very large negative values of the second control deviation  $dR2$ , the factor  $kp2$  is limited to a value  $GW3$ . A negative control deviation is present when the second actual speed  $nM2(IST)$  is greater than the set speed  $nM(SL)$ . At positive second control deviations  $dR2$  that are greater than the second limiting value  $GW2$ , the factor  $kp2$  is limited to the value  $GW4$ . In the region between the first limiting value  $GW1$  and the second limiting value  $GW2$ , the factor  $kp2$  is set to the value zero. It is apparent from the characteristic curve 14 that in the steady state, i.e., where the second control deviation  $dR2$  is almost zero, the factor  $kp2$  has a value of zero. Consequently, the P component 15 of the speed controller 11 is determined in this case exclusively from the first control deviation  $dR1$ . In the event of dynamic changes of state, i.e., where there is a large negative or positive second control deviation  $dR2$ , the factor  $kp2$  acts on the P component 15 of the speed controller 11. The P component of the power-determining signal is now computed as a function of the first control deviation  $dR1$  and the factors  $kp1$  and  $kp2$ :

$$ve(P) = dR1 \cdot (kp1 + kp2)$$

where

$ve(P)$  = proportional component of the power-determining signal  $ve$

dR1 = first control deviation

kp1 = first factor

kp2 = second factor

The factor kp1 can either be preset as a constant or computed as a function of the first actual speed nM1(IST) and/or the I component ve(I).

Another possibility for computing the P component ve(P) is to use the control deviation dR2 directly for the computation of the P component 15:

$$ve(P) = dR1 \cdot kp1 + dR2 \cdot kp2$$

where

ve(P) = proportional component of the power-determining signal ve

dR1 = first control deviation

dR2 = second control deviation

kp1 = first factor

kp2 = second factor

This embodiment is shown by the dotted line in Figure 3. The P component and the I component are added in the summation unit 18. The sum corresponds to the power-determining signal ve.

Figure 5 shows a functional block diagram of a second embodiment of the internal structure of the speed controller 11. In this embodiment, in contrast to the embodiment shown in Figure 3, the second control deviation dR2 is supplied to the P component 15 and simultaneously to a DT1 component 17. The DT1 component 17 computes the DT1 component ve(DT1) of the power-determining signal ve. The summation unit 18 then computes the power-determining signal ve from the addends of the P component, I component, and DT1 component. The DT1



component 17 is computed by a characteristic curve 19, which is shown in Figure 6. The time  $t$  is plotted on the x-axis. The y-axis corresponds to the DT1 component  $ve(DT1)$  of the power-determining signal  $ve$ . When there is a sudden change in the second control deviation  $dR2$ , it is assigned a corresponding value  $ve(DT1)$  by the characteristic curve 19. Two limiting values  $GW1$  and  $GW2$  are plotted on the graph. The DT1 component is deactivated if the second control deviation  $dR2$  becomes smaller than the first limiting value  $GW1$ , i.e., the signal  $ve(DT1)$  then has a value of zero. The DT1 component is activated if the second control deviation  $dR2$  becomes greater than the second limiting value  $GW2$ . The effect of the limiting value  $GW2$  is that, when there are dynamic changes of state, i.e., when the second control deviation  $dR2$  has large positive or negative values, the DT1 component is also incorporated in the computation of the power-determining signal  $ve$ . When a steady state exists, i.e., where the second control deviation  $dR2$  is practically zero, the power-determining signal  $ve$  is determined exclusively from the P component and the I component.

### List of Reference Numbers

- |    |   |
|----|---|
| 1  | drive unit                              |
| 2  | internal combustion engine              |
| 3  | transmission element                    |
| 4  | engine load                             |
| 5  | electronic control unit EDC             |
| 6  | fuel tank                               |
| 7  | pumps                                   |
| 8  | rail                                    |
| 9  | rail pressure sensor                    |
| 10 | injectors                               |
| 11 | speed controller                        |
| 12 | first filter                            |
| 13 | second filter                           |
| 14 | characteristic curve                    |
| 15 | P component (proportional component)    |
| 16 | I component (integral-action component) |
| 17 | DT1 component                           |
| 18 | summation unit                          |
| 19 | characteristic curve                    |